3S^2 - Behavioral Response Studies of Cetaceans to Naval Sonar Signals in Norwegian Waters

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LONG-TERM GOALS

One primary goal of this international cooperative research program is to investigate behavioral reactions and the sound exposures required to elicit them of three species of whales: bottlenose whales, minke whales, and humpback whales to Low Frequency Active Sonar (LFAS) signals. The results will be interpreted to generate dose-response functions, in order to help establish safety limits for sonar operations for these species.

Another primary goal of the program is to experimentally assess the effectiveness of "ramp-up," a common mitigation protocol in which source levels are gradually increased prior to the onset of full-level transmissions. Ramp-up is designed to give nearby animals some time to move away before sonar transmissions reach maximum levels. However, it is unknown whether or not this protocol is actually effective for animals in their natural environment. We have developed and implemented an experimental design to test whether the 'ramp-up' procedure is an effective protocol to reduce risk of harm from sonar activities.

OBJECTIVES

In this research project, our specific objectives are to: 1.) Expand the 3S comparative experimental dataset to include species that are potentially more sensitive and difficult to study: Northern bottlenose whale (*Hyperoodon ampullatus*, family Ziphiidae) and minke whale (*Balaenoptera acutorostrata*, family Balaenopteridae). The goal is to identify behavioural response thresholds during experimental exposures, and to compare these to responses to no-sonar controls and playback of killer whale sounds; 2.) Conduct a directed study of the effectiveness of ramp-up as a mitigation method with abundant and relatively easy-to-study humpback whales, *Megaptera novaeangliae*; 3.) Record sufficient no-sonar baseline data of all target species to adequately describe the behavioral significance of recorded changes in behavior and to statistically compare experimental records with baseline records; and 4.) Develop collaborations between the 3S research group with other research groups undertaking similar projects to pool data where appropriate, share expertise and reduce overall project costs.

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APPROACH

Two of the species of whale selected for this study are North Atlantic species for which there is evidence of risk from sonar exposure. Sonar-related strandings have commonly involved Ziphiids in temperate or tropical waters, but have also included species that are more common the North Atlantic: the Northern bottlenose whale (Canary Islands), and the minke whale (Bahamas). It is unclear whether the low numbers of Northern bottlenose whales and minke whales documented in sonar-related stranding events result from lower sensitivity to sonar or because they are present in lower numbers in the areas where documented stranding events have occurred. To resolve this question, directed research on the behavioral responses of these two species is needed (Tyack et al., 2004). The earlier 3S research effort (see related programs) with killer, sperm, and long-finned pilot whales provides a dataset that enables comparative analysis of behavioral response sensitivities. The $3S^2$ field experiments follow the same protocol of escalating the level received by the whale subject in order to identify response thresholds. Broader comparative data are also available from other research teams.

Similar experimental data are needed to address the question of whether or not 'ramp-up' is an effective mitigation measure. Animals located close to the location of the first full-level sonar transmission are at the greatest risk of severe effects such as strong behavioral responses or hearing effects such as temporary or permanent threshold shift (left panel of Fig. 1). The 'ramp-up' protocol could be effective if it gives animals time to move away from the immediate location of the full-level sonar pings (right panel of Fig. 1). Thus, the 'ramp-up' protocol is itself is based upon the principle of <u>behavioral response</u> – in this case an avoidance response that protects the animals from receiving intense sound levels.

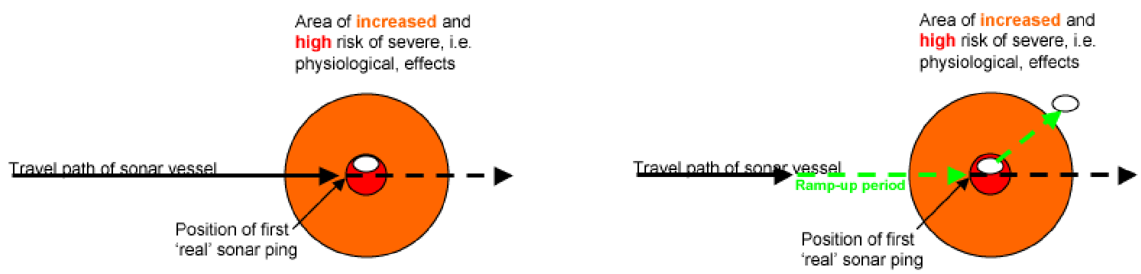

Figure 1. A conceptual diagram of the role of ramp-up before full-level sonar operations. Left: Animals near the position of the first full-power sonar transmissions are at a higher risk of severe physiological effects. Right: The use of the ramp-up procedure implies that sonar sounds are started earlier, at lower levels, and are gradually increased to full power at the planned position. These additional 'ramp-up' transmissions are thought to reduce risk by giving animals within the zone of increased risk time to move away.

Specifically, it is assumed that animals will move away from the source of sounds during 'ramp-up', even if the sounds are transmitted at relatively low source levels. Avoidance has been observed in several studies of marine mammals in the presence of noise (Richardson et al., 1995), but does not necessarily always occur (Miller et al., 2009). It is even possible that starting the sonar sounds at low levels will cause the animals to acclimate to the sound, thereby reducing any tendency to avoid the source. Second, it is assumed that animals will be able to sense the direction and path of the oncoming sound source and formulate a good direction to move away from the sound source. Moreover, it may

take some time for animals to determine the direction and speed of movement of the vessel to make appropriate avoidance movements.

To study the effectiveness of 'ramp-up' as a mitigation tool, we are quantifying the likelihood of avoidance as a consequence of exposure to the 'ramp-up' signals. Thus, it becomes critical to understand what factors affect the probability of avoidance (e.g. received level at the animal, distance of the source, frequency or amplitude of the sonar, sound propagation conditions, behavioral state of the animal). As in behavioral response generally, we seek to understand what the consequences for the animals are, but in the case of 'ramp-up' we specifically would like to know whether avoidance behavior leads to effective protection from high sound exposure levels or not.

The research is carried out by an international collaborative team from the Sea Mammal Research Unit (SMRU), Woods Hole Oceanographic Institution (WHOI), Norwegian Defense Research Establishment (FFI), and Netherlands Organization for Applied Scientific Research (TNO). WHOI provides v2 Dtags and tagging support for the field work. Project management and logistic support, including acquisition of research vessels and permitting are managed through FFI, led by Dr. Petter Kvadsheim. FFI also provides biological and tagging expertise, including the development of a new pneumatic launching system for the Dtag, headed by Lars Kleivane. TNO contributes an advanced towed array system for recording and detecting marine mammal sounds (Delphinus), a multi-purpose towed source (Socrates), and staffing during the cruises under the leadership of Frans-Peter Lam, with collaboration from René Dekeling of the Royal Netherlands Navy. The Socrates source is capable of transmitting 1-2 kHz signals at a source level of 214dB re1µPa m, and 6-7 kHz signals at a source level of 199dB re1µPa m. Miller of SMRU at the University of St Andrews leads the analysis team and Tyack also from SMRU is a member of the $3S^2$ board, provides scientific advice, and liaison with the WHOI tagging team.

WORK COMPLETED

In June 2012, we successfully conducted the second of three planned month-long experimental trials off Spitsbergen with the new target species: humpback whales, minke whales, and bottlenose whales. In this fiscal year, we also continued processing and analysis of data collected in the 2010 baseline trial and the first sonar trial conducted in June, 2011. Our team continued analysis of the baseline behaviour of 3S species to relate results from the 3S experiments (work done under the first increment of this award). Following our successful collection of additional playback of killer whale sounds to long-finned pilot whales and sperm whales in the 2010 baseline cruise under this award, the behavioral responses of those two species to the sounds have been analyzed. Each of the two species responded in a consistent manner, though the responses differed strongly between the two species. Results of these analyses have been presented at the 2011 ECS, ESOMM, International Bioacoustic Congress (IBAC), and Society for Marine Mammalogy (SMM) meetings, and the 2012 European Council for Underwater Acoustics (ECUA), and 4 papers have been prepared and submitted to scientific journals for peer review (see Publication list).

RESULTS

In the second research cruise of the current award, we operated in the same research area off Spitsbergen that we successfully established in the 2011 research trial. The 3S-12 research cruise took place between Tromsø and Svalbard, 70°-80° northern latitude and 3°-18° eastern longitude, June 1-30, 2012 using the Norwegian military research vessel H.U. Sverdrup II (Fig. 2). On this 2nd research

cruise of the award, a total of 389 sightings of an estimated 800 individual cetaceans were made. We deployed 16 Dtags, 13 to humpback whales and 3 to fin whales for a total of 172 hours of Dtag recordings.

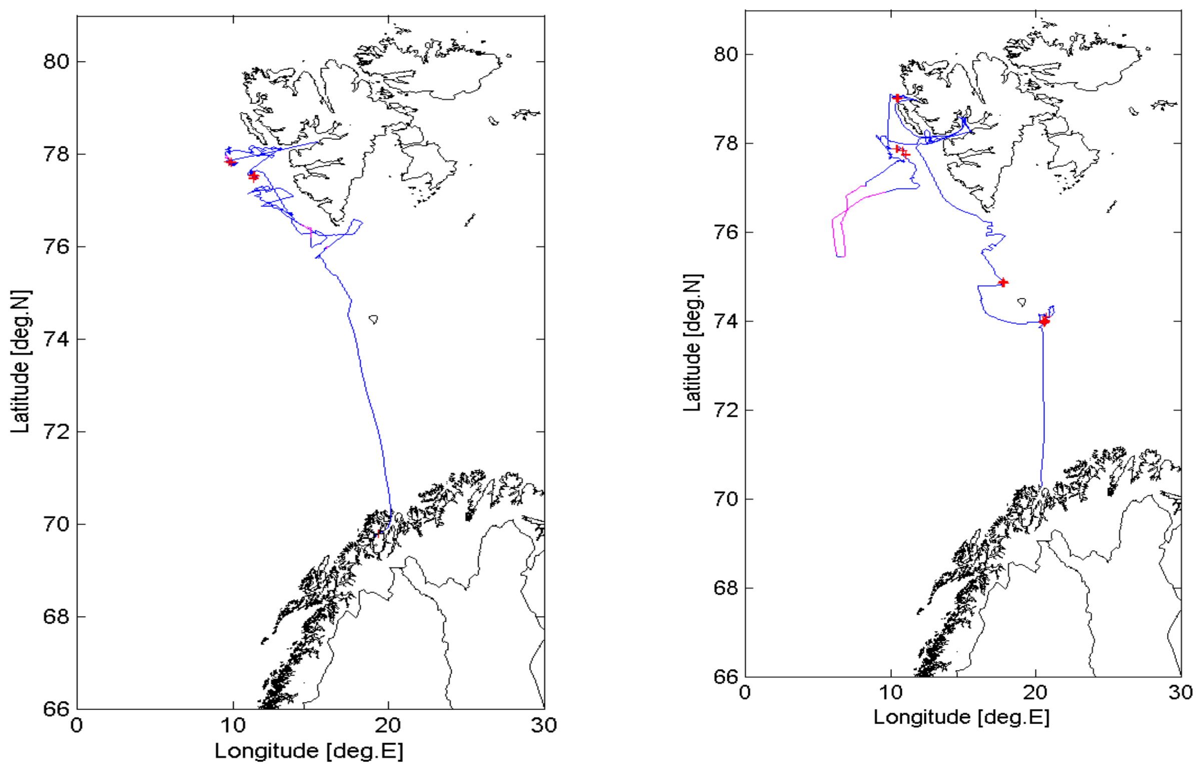

Figure 2. Sailing track of the HU Sverdrup II during the 3S-11 research cruise. The 1st leg (1-14 June) is shown on the left panel, and the 2nd leg (15-30 June) is shown on the right. Pink lines are track-lines with acoustic monitoring by TNO's Delphinus hydrophone array, and blue lines were transit with visual searching. Sonar transmissions by the Socrates source during experiments are shown in red.

Dtag deployments on humpback whales totalled 160 h of data, during which we conducted 7 full ramp-up experiments on humpbacks, including collection of pre-exposure baseline data, sonar exposure, and negative controls (silent approaches). In addition, playback of killer whale sounds as positive controls were conducted with 5 of the 7 whales. One 13 h record of baseline behavior was also obtained. All but one of the humpback whale deployments included position recording using a Sirtrac GPS logger attached to the Dtag. Unlike in 2011, tag attachments to humpback whales were reliable, remaining attached for the planned duration of the attachment. The ramp-up experiments were carried out successfully, with good data collection throughout each experiment.

We made substantial effort to attach a Dtag to minke whales during the trial using a minimally-invasive tag design developed in collaboration with other ONR PIs. A secondary tag, the Ctag designed by Lars Kleivane of FFI, Norway was also available for use, but was a secondary system relative to the preferred Dtag. Despite a roughly equivalent effort to that during the 2011 trial during which 5 tags were attached and one sonar experiment was conducted, no successful tag attachments were made to a minke whale during the 2012 trial. Also unlike the 2011 trial, we had no sightings of

the 3rd target species, the Northern bottlenose whale, despite search efforts for 2 days in areas where they had been sighted in 2012. After 2 of 3 planned sonar trials, we have now conducted 10 ramp-up experiments with humpback whales, one dose-escalation experiment to a minke whale (detailed below), but no tagging and no controlled exposure experiments with Northern bottlenose whales. We will adjust our efforts in the third trial, scheduled for summer 2013, to attempt to obtain a more balanced dataset for the total effort.

During this fiscal year, we analyzed in detail the behavioral record obtained from a minke whale during the 2011 trial. The whale was tagged with a 'Ctag', a small and light-weight tag anchored under the skin of the whale using a disinfected 60mm barb. The Ctag was deployed successfully on a minke whale on 19 June 2011, and released and was recovered following 19 hours of data collection. During the tag-attachment period, visual tracking of the whale was successfully accomplished from the observation vessel, which made it possible to conduct a sonar exposure experiment. In this first experiment with a minke whale, we were able to successfully collect pre-exposure baseline data, a silent vessel approach control, one sonar exposure and one playback of broadband noise. Inspection of the dive record (Fig. 3) clearly indicates little change during the silent exposure, but strong changes in diving behavior during the sonar exposure. The first dive during LFAS was the longest-duration dive in the entire record.

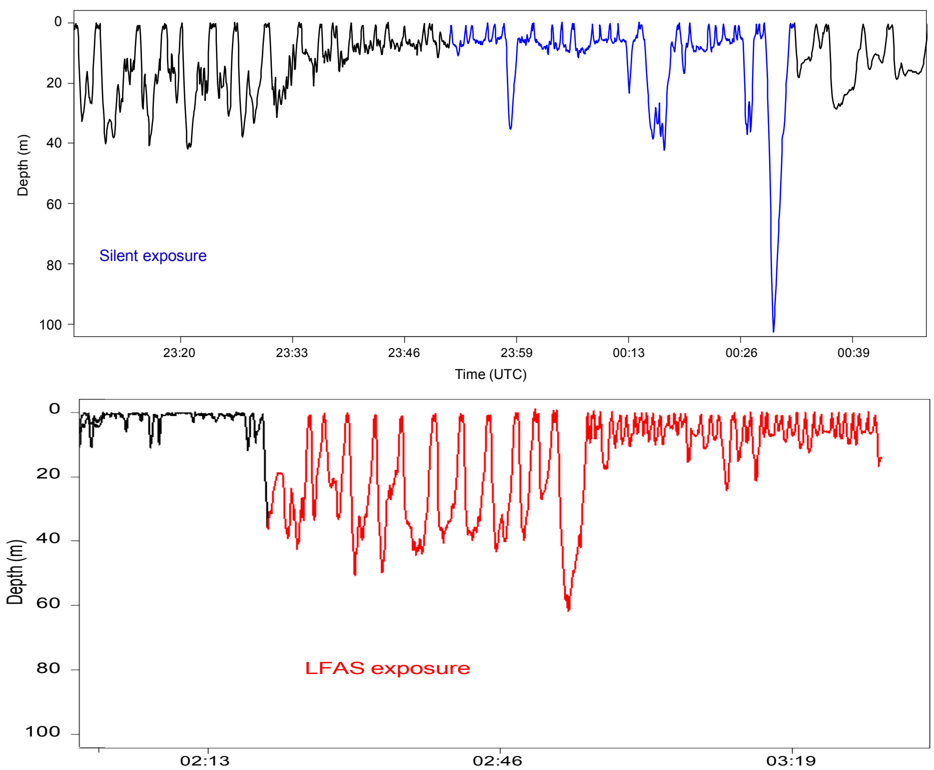

Figure 3. Dive pattern of the minke whale studied during the 2011 trial. Data are shown before, during and after the silent approach (top) and the 1-2 kHz LFAS exposure (bottom). Note the strong change in behavior during the sonar exposure, and limited change during the silent vessel approach.

The changes observed in the dive profile were coincident with a strong change in horizontal movement with the animal moving directly away from the sonar source (Fig. 4, top). Preliminary analyses of movement statistics of the tagged minke whale (Fig. 4, bottom) indicate that movement during the sonar exposure was at a higher speed, with more directed travel than during the pre-exposure period and the silent approach. Detailed inspection of the tag and track record indicates that the animal had two clear changes in behavior. The first was a change in dive behavior and movement away from the source very early in the exposure period when the source vessel was >6km away. A second change in behavior with the animal switching to shallow dives and increasing speed was apparent later in the record (Fig. 3, bottom) when received levels were higher and the source vessel was closer to the whale. Because the Ctag does not include an acoustic sensor, work is currently underway to estimate the received level associated with these changes in behavior using acoustic modelling and sound levels received on an array towed by the tracking boat near to the minke whale. Initial indications are that the whale began to respond to the sonar at very low received levels, potentially indicating that minke whales are highly sensitive to sonar. Additional experiments with minke whales to replicate this experiment with another animal are a high priority for this project in 2013.

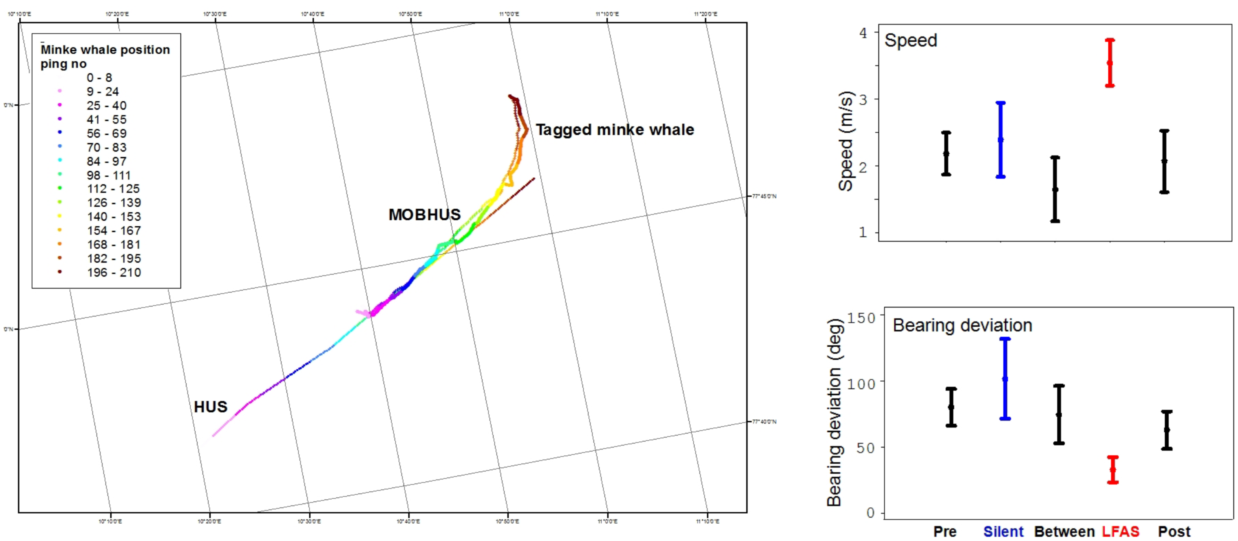

Figure 4. Movement track (left) and statistics (right) of the minke whale studied in 2012. Note the movement of the whale directly away from the source, at greater speed and reduced deviation in bearing during the sonar exposure.

Response of sperm whales to playback of killer whale sounds: Throughout the 3S project under award N00014-08-1-0984, and during the 2010 baseline trial under the current award, our team has successfully conducted playback of killer whale sounds to pilot whales, sperm whales, and humpback whales. We have now conducted 8 playbacks of mammal-feeding killer whale sounds to humpback whales, and early indications are that they respond more strongly and more consistently to killer whale playback than to exposure to sonar transmissions, but that the types of responses to the two stimuli are similar. This mirror our results with sperm whales, which have been analyzed in more detail over the past fiscal year. Sperm whale showed a statistically signficant decrease in dive duration and depth during killer whale playbacks (Fig. 5, left) though no change during noise control playbacks. Analysis of the types and consistency of changes to killer whale playback and sonar exposure indicate similar changes to the two types of stimuli (Fig 5, right), though responses to playback of killer whales are more consistent.

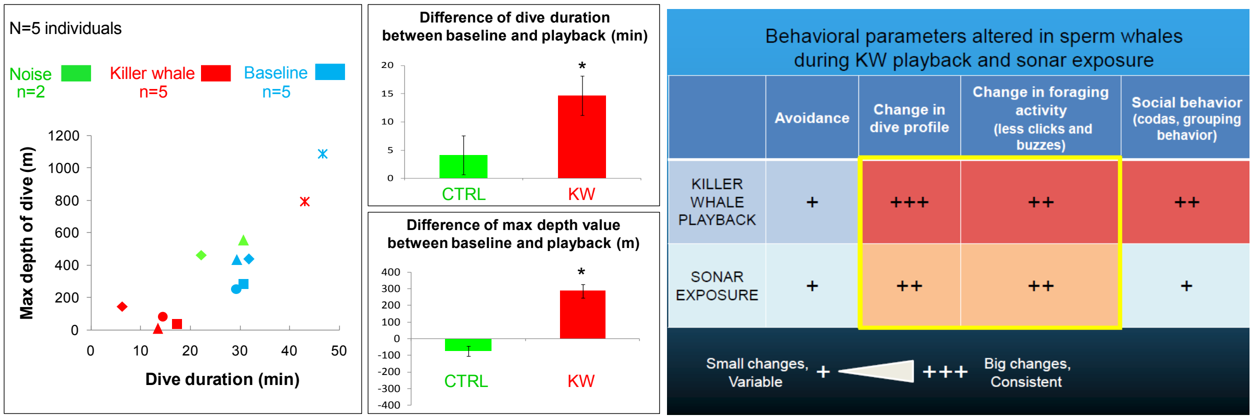

Figure 5. Results of playback of killer whale sounds to sperm whales (left), and contrast of responses of sperm whales to killer whale playback and sonar, right. Avoidance and social behaviour changes were recorded during both killer whale playbacks and sonar exposures to sperm whales, though they were less consistent than the changes in dive parameters.

RELATED PROJECTS

This study is an extension of the project "Cetaceans and naval sonar: behavioral response as a function of sonar frequency" award number N00014-08-1-0984, which expired in 2011. The project "Development of a pneumatic launcher delivery system for the new digital recording tag, DTAG3" to Alex Bocconcelli at WHOI, award number N000141110539, has developed new methods to attach Dtags for the $3S^2$ project.

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